Tyne and Wear Metro Delays: improvements and evaluation of performance using event based simulations

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Abstract

Tyne and Wear Metro has been operated by DB Regio Tyne & Wear Limited, which is a subsidiary of ARRIVA UK Trains under a contract to north East Combined Authority "Nexus" for some seven years. The quality of Metro service has been low and suffered from delays and poor maintenance. The objective of this study is to look at metro performance by creating an event based simulation model of Tyne and Wear Metro using Simul8 so that it can replicate the problems Metro is currently suffering. A solution is proposed and analysed using Simul8. Evaluation employed is based on the performance and practicability of the system in study. Comments and suggestions are then given to help Metro improve the on-time reliability and the quality of service.

Key Words: delays, Tyne and Wear Metro, event based simulation

I.Introduction

Motivation

Public transport is vital for society. It provides different methods to travel in the city, especially to those who do not have access to a private vehicle. Using public transport have quite a few advantages; reduce carbon footprint, enhance personal opportunities and provides economic opportunities & drives community growth and revitalization (APTS, 2016).

In Newcastle upon Tyne, one of the mostly used public transport is Tyne and Wear Metro. It is the second biggest metro system in the United Kingdom followed by London Underground. It opened on 11 August, 1980. It has two lines, Green line travel from Airport to South Hylton and Yellow line from St James to South Shields via coast. It is still in use nowadays and it has served over 40 million people in 2015 (Nexus, 2016a).

Tyne and Wear Metro is owned by Nexus and operated by DB Regio Tyne & Wear Limited, which is a subsidiary of ARRIVA UK Trains. Nexus conducts performance review every 4 weeks, which is released to the public. For the previous four reviews, for the periods: Nov, Dec 2015, Jan, Feb 2016, the percentage of trains arriving on time is roughly under 80%, where it was 67.05% for Nov 2015. The criteria for affordable delay set and used by Nexus is within three minutes later than scheduled or within 29 seconds earlier than scheduled. Comparing to other rapid transit systems like MTR in Hong Kong, which have a 99.9% on time arrivals, it could be concluded that the percentage of Tyne and Wear Metro car arrivals on time is low (MTR, 2016).

Recent event of delay is due to signal error or infrastructure malfunction, independent review on delay and mitigation for similar scope rapid transit is not popular. Furthermore, little research is done on the impact of delay in Tyne and Wear Metro. Interested reader is referred to Motraghi & Marinov (2012), Wales & Marinov (2014). By analysing the problem of delays and aiming for strengthening the metro system it is envisaged to improve the quality of service by improving the “arrival on time” rate, hence, improve the experience of everyday travel.

Objectives

The objectives of this study include: The first objective is to analyse and understand Tyne and Wear Metro system. The second objective is to find the cause, frequency and scope of the delay and quantify the information gathered so that different scenarios can be created later on. The third objective is to create a simulation model to replicate the current Metro system. For validation purposes the model should have similar performance as the current Metro. The forth objective is to come up with a solution to solve the delay problem and evaluate the impact of this solution on the performance of the whole system. Lastly to draw conclusions and give suggestions based on the result from the simulation model.

Methodology

Firstly, background research is conducted on the subject of general rapid transit systems and the delay mitigation. Secondly, Tyne and Wear Metro is being studied. Thirdly, frequency and cause of delays is being identified and classified into groups. Fourthly, the aftermath is identified followed by categories based on the scope of the delay. Fifthly, simulation program is being selected based on the functionality needed. Sixthly, a Tyne and Wear Metro simulation model is generated. Seventhly, data of delays and mitigation methods are imported into the simulation model generated. Eighthly, the simulation model is run with various of scenarios and delay mitigation solutions. Results are then recorded and compared. Finally, the preferred delay mitigation scenario is evaluated depending on the effect and the prevention of the aftermath.

II.Background

Metro System

Rapid transit are known as Metro, Underground, Subway. It is a form of mass transit, it's characteristics are to operate on exclusive right-of way, with no access for other vehicles or pedestrians (Transit, 2016). It is used to transport large numbers of passengers within urban area (Britannica, 2016). It has a few advantages in comparison to personal vehicle. First it has a high-capacity, it has the ability to transfer a large numbers of people quickly from one place to another, the actual number will vary according to the capacity of the train and the timetable. Second, lower energy consumption, 20% per passenger km in comparison to road-based system (RAIL, 2016). Third, Greater traffic capacity, metro has a very low ground space occupation, hence it can handle more passengers. On the other hand, number of stations is fixed, travel to or from rural area may not be possible. The timetable is fixed, missing a train can lead to waiting times for the next train to arrive.

Metro systems can consist of one or more lines, where each line will have its specific route and stations to stop at. Most of the metro systems have more than one route and are recognised by either names or colour, depending on the named system. Different lines can share the same track on part of the route to increase the frequency, usually near the city centre. Those stations are interchange stations for passengers switching from one route to another. There can be more than one terminal station for the same route. For example Tyne and Wear Metro Yellow line can be terminated at Pelaw or South Shields.

Tyne and Wear Metro

The total length of track is 74.5km, but only partial of the network is replicated on the average ridership in the area, which may have some impacts when a delay occurs. In (Wales & Marinov, 2014) Tyne and Wear Metro has been simulated, analysing train movement from 10am to 3 pm with a train departure at a regular interval of 12 minutes. In this article, a similar model is setup but extended the parameter from 5:30am (the first train) to 01:30am (where the last train will terminate), where at peak hour (07:00-09:00) (06:00-18:00) there is a train every 3 minutes. During this period a small delay can cause vast inconvenience to passengers.

For on board passenger information, there is a system call Fassi install in every train cab, driver can provide live announcements as long as it is safe to do so. (Nexus, 2013) One of the main problem of the current Tyne and Wear Metro system is out of date infrastructure and equipment. Some of the tracks are from old railway works. These tracks and some of the equipment has already served longer than its design estimate life spend. These items are a potential thread to the system, without proper maintenance, it could cause a major delay and failure.

Another potential problem of Tyne and Wear Metro is track signalling, in passenger charter, a monthly report that reflects the performance of Metro, showed that each month there is at least one disruption related to signal problem. Track signal error restricts the speed of train; this could lead to train stopping and affecting train punctuality as well as prevent the Metro system to recover if a delay already occurred before the signalling fault.

In the report for period End 27 February, 31 March, 30 April, 2016 there were more than 6 disruptions that occurred in every period. These delays were caused by different factors. One of the most occurring factor is signalling error fault in different area (mostly Whitley Bay Area). Track circuit fault also occurred frequently, suggesting the track is a potential problem and needs to be address.

Aftermath

No doubt, delay will be a lose-lose situation for both company and passengers. Depending on the scope of the delay, the number of travellers affected varies. Frequent delays may lead to a decrease in ridership and people losing faith in public transport, hence more use of peroneal vehicles. This could cause more traffic problems in peak hour.

Other consequence for delay includes company paying fines. In recent years, Metro operator has been fined £500000 in January, 2014 (bbc, 2014) and £271000 in July, 2015 (chroniclelive, 2015). The Metro operator may not be 100% liability for each of the disruptions but as an operator, they have the responsibility to keep the delay as little as possible. If the operator does not keep up the standard or improve, it will only be penalized more in the future.

Forms of delay

Delay is defined as arriving 29 seconds ahead of the scheduled time or arriving within 3 minutes or latter than 3 minutes of the scheduled time, this is defined as delay by

Tyne and Wear Metro (Nexus, 2016b). Delay is then separated into two categories; primary delay and knock-on secondary delays, the terms are defined by Vromans, Dekker and Kroon (Vromansa, , et al., 2006).

Primary delay is defined as initial delays caused on a train from the outside and not by other trains (Vromansa, , et al., 2006). This is usually caused by signal malfunction, bad weather, and infrastructure malfunction. An example for primary delay would be the incident that happened on 16, March 2016, when Tyne and Wear Metro has a signalling fault at Whitley Bay (Nexus, 2016d), then the train had to slow down, thus causing the train to delay upon arriving in another station.

Secondary delay is defined as delay cause by earlier delay as known as knock on delay. (Vromansa, , et al., 2006). It is not cause by other reason but a primary delay. An example for this would be an accident that happened on 4 April 2016 (Chronicle, 2016). A train failed to function between Monument and South Gosforth, every train followed by that train was delayed. Those delays are considered to be secondary delays since the delay was caused by a train break down which is classified as primary delay. In this article, we mainly focus on secondary delay and how fast can the system recover from the secondary delay.

As defined previous, primary delay is initial delay. This includes signal failure and train failure. From a driver perspective, each metro car is installed with Fassi system which makes it possible for the driver to get the necessary information on the condition of track, traveling speed, etc. on to the passengers. The driver can adjust the speed of the train to catch up to the schedule if late or slow down if arriving early. From a Nexus perspective, a message can be announced through social media or information board in station to notify travellers if a delay has happen. To prevent the problem happening at the first place, Metro should increase the frequency of quality checks and track maintenance or upgrade the system to reduce flaws.

However, Natural phenomena, for example in 2014, the flooding in Newcastle area (Chronicle, 2016a) caused a huge impact on the Metro system and considered unpreventable. To reduce the damage from these kind of unpreventable cause, infrastructure should be improved or upgraded to be more weather resistant.

Since secondary delay is a result of primary delay, in order to reduce the impact, one of the methods is to adjust the timetable. By increasing the time in between each train, the train is less likely to be affected by the ahead train or affect the following train. Another method is to reduce station waiting time or reduce inter-station time, this can help the Metro system to recover faster and reduce further secondary delay occurring. For Tyne and Wear Metro, on average if the train delay is no more than 15 minutes in non-peak hour, secondary delay is not likely to occur since the train is 12 minute apart and has more time to recover comparing to peak hour.

III. Simulation

Simulation program

In order to simulate the delay event and the performance of the current Metro accurately, a discrete event-based simulation program is used. Discrete event-based simulation (DES) makes it possible to simulate the sequence of events in a system, where each event change, the state of an entity, time and state change are recorded (Karnon, et al., 2012).

Simul8 is a software designed by Simul8 Corporation, with the purpose of modelling anything with a flow of work. For example, manufacture assembly line and call centre. It can read and write from databases, and drive SIMUL8 from other interfaces like Microsoft Excel, VB, and C++ (Simul8, 2016) .

Each work item will represent individual train and the simulation parameter will be from St James to Central via the coast (Yellow Line) and Regent Centre to Central (Green Line). The model is made out of different function blocks.

Every flow will require at least 1 start point to import the entities into the system being simulated. Multiple start point is used in the simulation model in order to give visualization of train depart from different location.

Activity block simulates the process of the entity go through. The process time can be fixed or set as random within a certain range. In the simualtion model, each station and track in between each station is representing by activity blocks.

Queue block is where entity store and wait for next block to be available. Queue block is used to represent the track in between different stations. The disadvantage is that the time consumed is fixed and cannot be altered.

End block is where work item ends its service. In the simulation model, multiple end block is added to indicate where the train is originally from. This gives a clearer result for those trains travelling from a specific start point to a specific end point. End block also shows the result of receiving work items.

Route is signed with arrows to indicate the direction of the flow of work items. In the simulation model, the flow moves anti-clockwise showing the trains start from St James and end at Newcastle Central. Multiple route is used in some stations for different destination, also when a train is terminating or keeps working.

To identify the impact of the delay on a daily operation, a weekday is chosen to be simulated. Weekend (Saturday) can be analysed but since match day will increase the usage for a certain period causing bottlenecks in the system hence only weekday result is of interest. The result is the mean travel time from St, James to Central station.

Label allows adding attribute to work item, for example, in this simulation, all trains travelling and terminating at Newcastle central are labelled with Central and a number 1. Whenever the work item travels to a station with two different exits, it checks the label and the attribute to determine its direction.

The routing out function determine which route the entity advance. In this study the routing out function, depend on the label. For example, if a train is label with terminate at Longbenton, when the train arrive queue for Longbenton (the track just before arriving Longbenton), it will switch and enter the Longbenton end terminal.

Schedule is a function for other block, its purpose is to export train for specific station at specific time, and it can modify the label value for each specific train export.

The clock refers to the time in virtual environment. It is shown in digital clock format. The simulation start time is 00:00; duration of the day is 24 hours. Warmup period is 18000 seconds. No data is recorded in the warmup period. This reduces the necessary storage for the result. The result collection program is 73800 seconds. In other word, program start from00:00 then start record at 05:00 and end at 01:30(next day). For peak hour, the warmup period is 2 hours. The result collection period is also 2 hours.

The system layout is shown as Figure 5.1. The train will travel from St. James and terminate at Central via the coast in anti-clockwise direction.

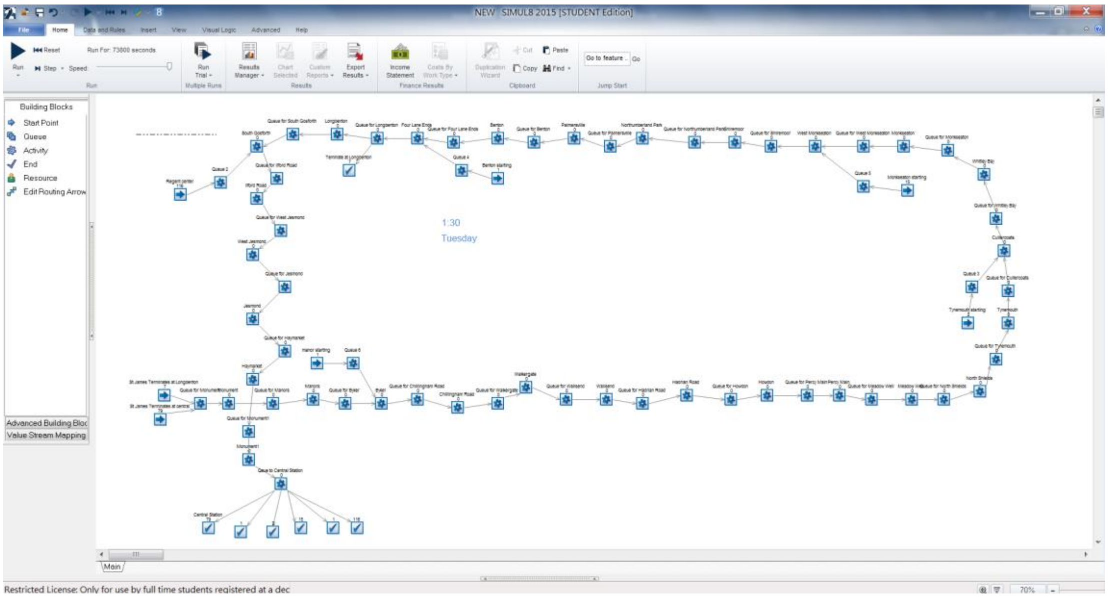

Figure 5.1 show the Tyne and Wear metro from St James to Central station via the coast

To ensure the program is accurate, a control test is done. Departure schedule is taken from Nexus metro homepage. The inter-station travel time is calculated from looking at the timetable. These data are inputted to the simulation model. No delay is included in this stage, and the result is then compared with the actual timetable. It is also indexed if any delay is added into the system.

Visual logic is SIMUL8's built in simulation language. Logic serve the purpose to change variable value base on the condition given. In this simulation, inter-station time is set with a fix time plus a variable; when the fix time plus the variable is lower than a certain fix time, the visual logic will change the inter-station time to minimum require time. Figure 6.1 and 6.2 are examples of using visual logic.

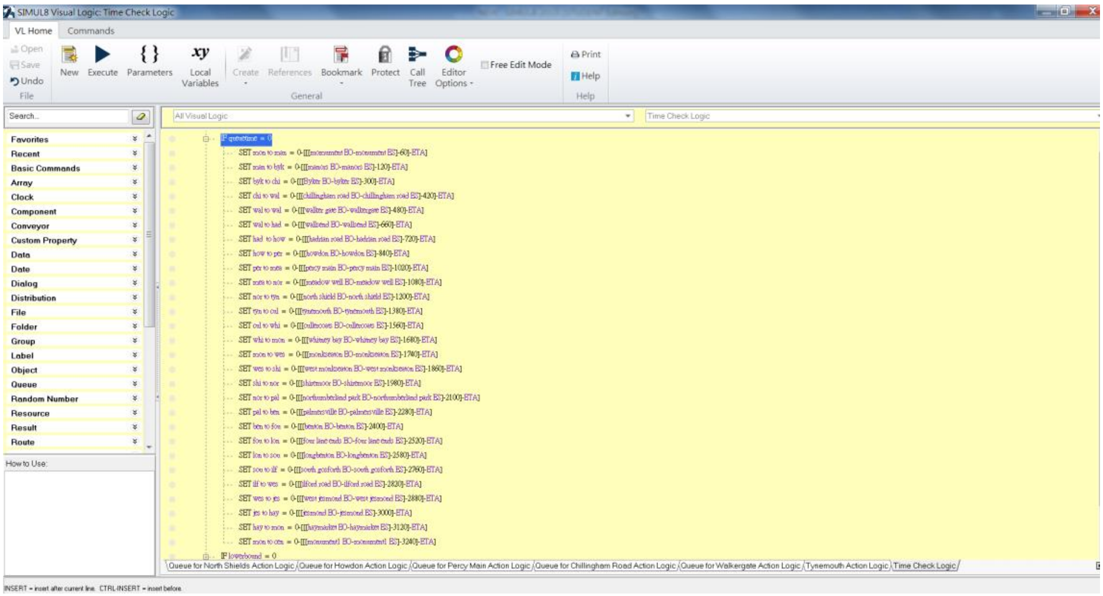

Figure 6.2 Code to modify the interstation time

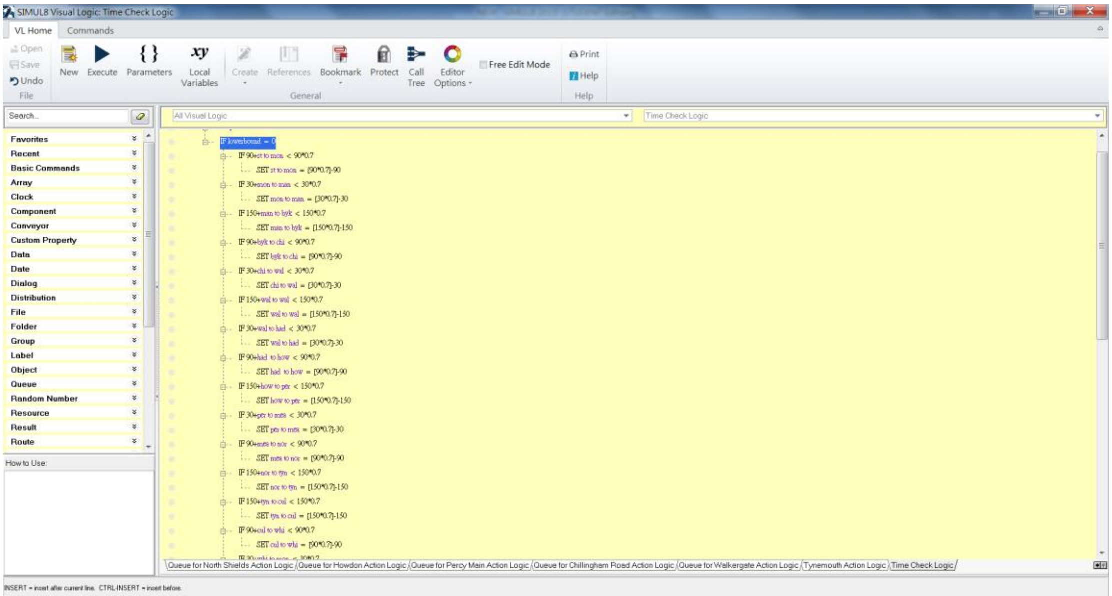

Figure 6.3 Code to prevent train achieving impossible interstation time

A visual logic is generated to tackle some of the simulation problems. For example the driver controls the speed of the train in order adjust the arrive time. This phenomenon is simulated by changing the inter-station time, the time of the train enter the model and the station will be record and then compare to the scheduled time. If it is too early, it increases the next journey before arriving next station, vice versa. The code for all the station is shown in Figure 6.1. For South Gosforth to Central, since it is share by 2 lines, and if function is added to identify the origin of the train so it modifies the interstation time correctly.

Since the interstation time is modified by the item enter station time and item enter system time, the modified time can be negative which at current technology is impossible to execute. In order to solve this problem, another visual logic is generated. Assuming 30 % of the scheduled travel time can be reduced, the modified travel time is not going to be lower than 70% of the original.

Three scenarios are modelled to simulate the real world situation.

The first scenario simulates a single delay fault; the specific track has speed limit hence the inter-station travel time increases by a specific amount. It can be tested if the train spends more time than its scheduled time and how well it can be recovered from a delay. It is predicted that metro can recover from this scenario.

The second scenario is simulating a minor delay with 90% efficiency for every station. This means there is a 10% chance for the station to be down and the repair time is to be 60 seconds. It is also predicted that the Metro model can recover from this scenario.

The third scenario simulates a major failure with 99.9% for every station and track. There will be a 0.1% chance that the station or track are to be down for 1800 seconds. For this scenario, it is predicted that the Metro is not going to recover from this scope of delay in a short period of time.

IV.Results

Collection of results

The result is collected and exported into a table, e.g. Table 2; the abbreviations in table 1 are used. The minimum, mean and maximum travel time, the standard deviation, the percentage of train arrived within a specific time limit, indicating how punctual the train is.

d0	w/o mitigation	SD	standard deviation
d1	w/ mitigation	T3240	% within 3240sec
min	minimum travel time	T3300	% within 3300sec
mean	mean travel time	T3480	% within 3480sec
max	maximum travel time		

Table 1 Abbreviations used

Table 2 shows the control result. No delay is added into this scenario. From the result, for St. James, with and without delay mitigation have a mean travel time between 3300 and 3330, the result is almost identical to the scheduled travel time which is 3300. Hence, this is validated. For Airport, mean time is also close to the scheduled time of 560 seconds.

	control	d0		d1				
	St. James	airport		St. James	airport		difference	difference
min	3081.77	431.51		3261.59	533.37		-179.82	-101.86
mean	3332.71	572.12		3300.66	560.11		32.05	12.01
max	3590.19	678.21		3329.84	593.08		260.35	85.13
SD	116.67	43.68		10.85	9.64		105.82	34.04
T3240	27			0				
T3300	41			48				
T3480	89			100				

Table 2 Control results

For a control group, by referring to Metro definition on delay, total travel time within

3240 seconds and 3480 seconds is considered on time. When no mitigation method is applied, only 62% arrived on time, when mitigation method is applied 100% of the train arrived on time.

Table 3 shows scenario 1, which is a single delay in Manor station for 600 seconds. From Manor to Newcastle Central, there are 27 stations in between and more than 2800 seconds to let the system recover from a potential delay. This scenario is to test how the system recovers in a long distance. Comparing with the control result, without any delay mitigation, the mean time increases roughly with 600 seconds, which equals to the delay input. When with delay mitigation, the mean time increases with 43 seconds, which is a 93% reduction in delay.

	delay at manor 600s	d0		d1				
	St. James	airport		St. James	airport		difference	difference
min	3403.39	410		3262.31	533.37		141.08	-123.37
mean	3924.77	543.57		3343.72	560.46		581.05	-16.89
max	4350.99	647.53		3635.06	586.48		715.93	61.05
SD	218.08	44.04		90.41	9.47		127.67	34.57
T3240	0			0				
T3300	0			41				
T3480	1			89				

Table 3 Scenario 1 - results

Table 4 shows scenario 2 in which all stations have a 90% chance of delay for up to 60 seconds. For without delay mitigation, the mean travel time is 3600 seconds, which is 300 seconds more comparing to the control result. When delay mitigation is implemented, the mean travel time drops to 3336 seconds, which is a 88% reduction in delay.

Scenario 3 is shown in Table 5; it shows a 99.9% chance of delay for 1800 seconds. The result is very similar to the control test, indicating that during the simulation no delay occurred. A delay occurs at 0.1%, which is most unlikely to happen.

	90% 60s	d0		d1				
	St. James	airport		St. James	airport		difference	difference
min	3220.01	450.62		3262.9	533.37		-42.89	-82.75
mean	3600	601.49		3336.14	579.23		263.86	22.26
max	4581.55	940.31		3636.18	841.61		945.37	98.7
SD	248.72	90.66		76.17	50.14		172.55	40.52
T3240	4			0				
T3300	6			32				
T3480	33			92				

Table 4 Scenario 2 - results

	99.9 1800s	d0		d1				
	St. James	airport		St. James	airport		difference	difference
min	3072.45	410.1		3261.59	533.37		-189.14	-123.27
mean	3328.99	543.59		3300.18	560.23		28.81	-16.64
max	3646.39	647.53		3329.84	593.07		316.55	54.46
SD	126.38	44.27		11.31	9.55		115.07	34.72
T3240	27			0				
T3300	43			49				
T3480	87			100				

Table 5 Scenario 3 - results

In order to evaluate the secondary delay and mitigation, 2 extra time frames are selected. The period is peak hour where train can depart every 3 minutes in some stations. Secondary delay is more likely to occur if a primary delay occurs in peak hour since there is less time for the system to recover. In Table 6 to Table 8, these are the results for peak hour in the morning from 07:00-09:00 and in Table 9 to Table 11 for the afternoon from 16:00-18:00.

Table 6 shows the control result for 07:00-09:00. The standard deviation reduces when mitigation method is applied. The improved time is much closer to 3300 seconds.

	control	d0		d1	
	St. James	airport		St. James	airport
min	3247.66	463.06		3277.26	521.29
mean	3344.98	566.69		3300.26	557.12
max	3515.55	648.22		3314.05	576.26
SD	101.86	49.23		9.87	12.63
T3240	0			0	
T3300	33			40	
T3480	78			100	
Number of train	9	21		10	21

Table 6 Control result from 07:00-09:00

Results from Scenario 1 from 07:00-09:00 are summarised in Table 7. The mean time without mitigation method is 3856 seconds, when the mitigation method is applied the mean time is 3336 seconds with a 13.5% reduction in time.

	delay at manor 600s	d0		d1	
	St. James	airport		St. James	airport
min	3635.05	488.71		3277.26	521.29
mean	3856.17	571.67		3336.62	556.11
max	4140.76	677.44		3460.89	573.96
SD	165.61	49.6		63.48	11.74
T3240	0			0	
T3300	0			20	
T3480	0			100	
Number of train	10	21		10	21

Table 7 Scenario 1 results from 07:00-09:00

In Table 8, this is Scenario 2 from 07:00-09:00. The mean time without mitigation method is 3575 and with the mitigation is 3314, showing that a 7% of time is reduced.

	90% 60s	d0		d1	
	St. James	airport		St. James	airport
min	3371.05	501.35		3293.23	521.29
mean	3575.87	615.61		3313.97	589.64
max	3777.44	819.86		3364.13	744.13
SD	159.7	819.86		22.54	61.25
T3240	0			0	
T3300	0			30	
T3480	40			100	
Number of train	10	22		10	21

Table 8 Scenario 2 results from 07:00-09:00

Table 9 shows the control test from 16:00-18:00. The mean time is 3337 seconds and with the mitigation method, it is 3295 seconds with a 14% reduction in time.

	control	d0		d1	
	St. James	airport		St. James	airport
min	3190.97	490.43		3273.37	554.61
mean	3337.72	563.75		3295.54	563.05
max	3532.08	673.2		3305.85	573.19
SD	130.99	54.77		9.47	5.62
T3240	44			0	
T3300	44			70	
T3480	78			100	
Number of train	9	10		10	10

Table 9 Control result from 16:00-18:00

Table 10 shows Scenario 1 from 16:00-18:00. The mean time is 3903 seconds and with mitigation, method is 3298 seconds. A 15.5% of time is reduced.

	delay at manor 600s	d0		d1	
	St. James	airport		St. James	airport
min	3649.59	462.6		3273.37	554.61
mean	3903.2	586.77		3298.24	563.05
max	4158.81	639.2		3325.82	573.19
SD	145.84	49.43		14.17	5.62
T3240	0			0	
T3300	0			56	
T3480	0			100	
Number of train	10	10		9	10

Table 10 Scenario 1 results from 16:00-18:00

Table 11 shows Scenario 2 from 16:00-18:00. The mean time is 3620 seconds and with mitigation, method is 3328 seconds. A 8% of time is reduced.

	90% 60s	d0		d1	
	St. James	airport		St. James	airport
min	3356.72	593.51		3274.5	558.33
mean	3620.48	695.03		3328.53	615.59
max	3805.78	867.28		3450.94	759.27
SD	128.83	82.95		50.84	69.13
T3240	0			0	
T3300	10			30	
T3480	40			100	
Number of train	10	10		10	10

Table 11 Scenario 2 results from 16:00-18:00

Discussion

The mitigation method is predicted to reduce secondary delay and prevent primary delay happening due to over speed. Referring to Figure 8.1, after applying a tactic from all trains, start from St. James tends to finish at around 3300 seconds, which is the scheduled time for the full journey. In the result, it is also shown that the standard deviation is smaller; this points out the train travel time is more consistent. For train start from Airport, refer to Figure 8.2, the train has a similar trend of approaching the scheduled timetable.

Figure 8.1 Bar chart showing travel time starting from St. James

For Scenario 3, the result is similar to the control result. This could be one of the following two reasons: first reason, there is no delay happening in the simulation, thus the result is the same and second reason, there is a delay happening but the system recovers really well so the result is the same as the control result. The first reason is more likely to happen, since 99.9% chance of not happening has a relative low chance of occurring. Hence, in order to find the reason, a longer simulation is needed. This might also indicate that if Tyne and Wear Metro can keep their services at 99.9%, Metro should be able to increase the "on-time" reliability.

As previously mentioned, Tyne and Wear Metro only gets around 80% of on-time reliability, but in the simulation, the on-time reliability is much higher. This is because, it only considers a single journey to Newcastle Central but in Metro review it considers every train arriving at every station, when secondary delay occur, all affected trains will be delayed hence more trains are affected.

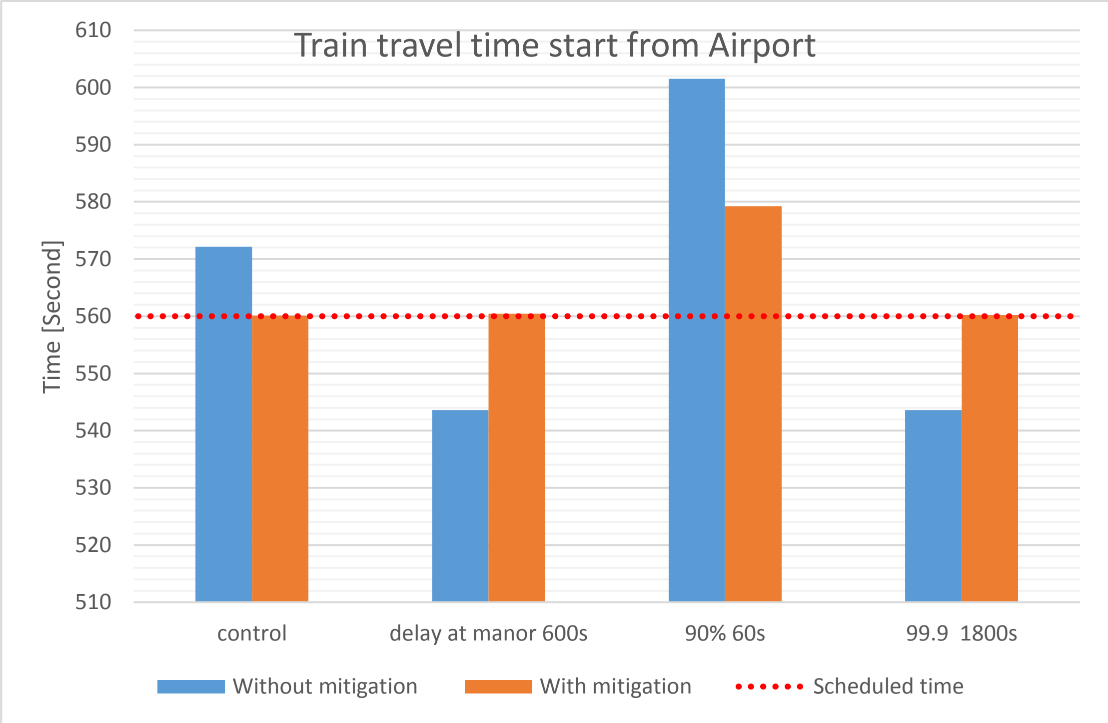

Figure 8.2   Bar chart showing travel time start from Airport

In a virtual environment, the mitigation method proves that it can improve and help the system recover quicker from a delay. In a real world environment, Metro has a control system to tackle delays, but the "on-time" reliability is still low, this might be due to other factors in the system.

In order to improve the on-time reliability, other areas can also be worked on. Firstly, switch the train from manual drive to automatic train operation, most specifically using GoA3 or GoA4 system. For these types of systems, starting and stopping the train can be controlled by a computer. If a human being is driving, it can be influenced by a few factors, say: the condition of the body, the attitude of the driver (DMV, 2016) or a lack of experience. Computer does not suffer from the above problems and hence can achieve higher efficacy and spend less operating time.

Another solution is to upgrade the infrastructure, hence the frequency of track circuit fault and signal error fault should decrease, thus an increase in train reliability.

V. Conclusions/Recommendations

The purpose of the current study was to identify improvements for Tyne and Wear Metro performance. A simulation model is created using Simul8 to help understand the Metro performance. The model is validated against the Metro timetable. Three scenarios are modelled. First one is at a fix delay of 600 seconds applied in Manors. Second one is a 90% efficient with average down time of 60 seconds. Third one is a 99.9% efficient with average down time of 1800 seconds.
Before proceeding to examine the impact of all three scenarios, a mitigation method is generated to tackle the problem. On average, all the delays tend to reduce and the travel time is more consistent. With regard to Scenario 3, the result is similar to the control result, where it is assumed no delay happening in this scenario; further research is needed in order to learn about this situation. This result also suggests that if Tyne and Wear Metro can maintain a 99.9% efficient, the train reliability should be improving.

The research work has also shown a few suggestions to further improve Metro performance. The use of computer control for starting and stopping trains. This can decrease the chance of delay cause by human error. Another recommendation is to replace or upgrade the physical element of system, e.g. infrastructure. Since some of the faults are caused by physical parts becoming old, hence swapping them out should help decrease both circuit fault and signal fault.

Future work

First, the simulation program is a student version, this means some of the commercial version functions are excluded. These functions are designed to help better simulate the system model, or make a more sophisticated model. For example, one of the functions is letting use of visual basic code or C++. Visual basic and C++ is another coding software that can perform tasks with simple codes, it is similar to visual logic in Simul8 but it can perform more tasks and can execute much more variety of commands.

Another problem is a lack of accurate data, in order to create a 100% model matching the Tyne and Wear Metro, more data is needed from Nexus, but since some of the data is confidential or for internal use only, part of the model structure have been developed based on expert evaluations, the uncertainty should be eliminated to improve accuracy.

The software being a student edition, some of the functions are blocked. By using these functions, the model code can be more simplified and more factors can be added into the model to perform a more realistic simulation. For example, input the real time metro performance and predict the punctuality or using the visual basic (add on for Simul8 for professional version) to simulate delay mitigation like skipping a station to recover from delay faster.

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